

METHOD AND APPARATUS FOR ULTRASONIC IMAGING USING ACOUSTIC BEAMFORMING

The invention relates to a method and apparatus for ultrasonic imaging, and in particular,
5 to ultrasonic imaging utilizing acoustic receiver beamforming techniques.

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims priority of Italian Patent Application Serial No.
SV2002A000058 filed November 28, 2002, which is hereby incorporated by reference in its
10 entirety.

BACKGROUND OF THE INVENTION

Among the various ultrasonic imaging techniques, one technique provides focusing of at
15 least the received beam, but typically both the transmitted beam and the received beam, to a scan
area, point or line which extends through a certain depth in the body under examination, from the
transmission surface of the transducers into the body under examination.

During beam transmission, the acoustic energy generated by the transducers are
concentrated upon the particular area, line or point. During beam reception, beamforming
20 techniques are used to receive and synchronize the components of the signals received by the
receiving transducers, and reflected by the particular area, line and point.

The time delays imparted to the reflected signals are a function of the propagation
velocity of acoustic waves in the body under examination, of the steering angle of each
transducer relative to the reflection line or point, and of the position of each receiving transducer
25 in its array. Transducer arrays of ultrasonic probes may be of different types, provided that
transducers are arranged side-by-side over at least one straight or curved line, or over a flat or
curved surface.

In other types of probes, a transducer array having a smaller number of transducer is
translated or rotated to cover a wider field of view. With a few obvious variants, the above
30 method also applies to these types of transducer arrays, by simply accounting for their movement
during scanning.

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In the latest generations of ultrasonic imaging apparatus, especially those used in combination with contrast agents, imaging is based on the part of the received signal which frequency is a harmonic of the fundamental transmission frequency. In this case, the fundamental frequency component of the received signal must be separated and/or suppressed to allow imaging. This is mainly due to the fact that the fundamental frequency component of the signal has a much higher amplitude than harmonic frequency components, such that it generates imaging noise.

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In prior art, separation of the second harmonic component of the received signal from the fundamental transmission frequency component is obtained by using various techniques. One of these techniques provides the use of adaptive filters which require a greater computational load in the received signal processing process, and also require a certain knowledge of the received signal.

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Other techniques for separating the second harmonic component of the received signal from the fundamental frequency component use a double firing of acoustic pulses wherein the corresponding received signals are combined in such a manner as to cause the suppression of the fundamental frequency component.

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One of these techniques is, for instance, the so-called "pulse inversion" technique, in which two transmit pulses are phase inverted and their received signals are summed. These techniques avoid the use adaptive filters, but require double imaging times as each scan line require the transmission of an additional ultrasonic pulse.

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US 6,193,663 discloses a medial diagnostic ultrasonic imaging system which acquires received beams from spatially distinct transmitted beams. The transmitted beams alternate in type between at least first and second types across the region being imaged. The first and second types of received beams differ in at least one scan parameter other than transmission and receiver line geometry and can, for example, differ in transmission pulse phase, transmission focus, transmission or receiver aperture, system frequency complex phase angle, transmission code or transmission gain. Received beams associated with spatially distinct ones of the transmitted beams (including at least one beam of the first type and at least one beam of the second type) are then combined. In this way, many two-pulse techniques can be used while substantially reducing the frame rate penalty normally associated with such techniques. The transmitted beams are transmitted at different times. The delays used for forming the received beams depend

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only from the direction, i.e. the so called steering of the beam and from the position of the transducers forming the probe.

US 6,186,950 also discloses an ultrasound imaging apparatus combining the received beams generated from different transmitted beams transmitted at different successive instants.

5 US 6,193,663 and US 6,186,950 do not modify the classical techniques of beamforming, either for the transmitted beams and for the received beams.

The invention has the object of providing a method like the one described hereinbefore, which allows to separate the fundamental frequency component of the receive signal from the component at one of the harmonics, especially the second harmonic, of said fundamental
10 frequency, by using a method which is as simple as the methods that allow such separation by combining the receive signal of two successive identical transmit pulses without requiring said double transmission, thereby reducing imaging or scanning times.

BRIEF SUMMARY OF THE INVENTION

The present invention solves the above problem by providing a method wherein time delays are also calculated as a function of the operating frequency and of the position of each transducer to which receiver signals delays are applied. The delay calculation function may be of any type. The dependence of the position of the transducers to which receiver signals delays are imparted may be of the linear or non linear type.

Particularly, the invention provides the addition of a term to the delay calculation function, with the term depending from the frequency of the desired signal component and also being linearly or non linearly dependent from the index of the corresponding receiving transducer, i.e. from the position thereof in an array of receiving transducers.

The delay thereby determined is a function of the selected frequency component of the received signal to be used for image data transformation, whereby a phase shift is introduced which automatically suppress the fundamental frequency component while summing the signals of the receiving transducers.

With particular reference to Harmonic Imaging, i.e. to the use of second harmonic components of signals to generate image data, the dependence of time delays from the second harmonic frequency causes a phase shift of received signals which, when the signals from the receiving transducers are summed, causes automatic suppression of fundamental frequency signal components, whereas the harmonic frequency signal components are in phase with each other and those components are summed in a non destructive manner, thereby forming an amplified signal of second harmonic frequency components.

Since received signals are not continuous but pulsed signals, edge effects occur, such that phase shifted pulses partly overlap, whereby, in the simple embodiment of the method as described above, fundamental frequency components of the received signal are not completely suppressed and amplification is reduced in combination with a longer pulse duration for harmonic frequency components, particularly those at the second harmonic of the fundamental frequency.

In order to further suppress these side effects, the invention provides a variant in which the phase shift direction of successive signals is changed with reference to the moment in which they are received from the corresponding transducer of the transducer array, so that the phase

shift is kept substantially constant for fundamental frequency components and for the components at the selected harmonic, particularly the second harmonic, respectively.

A variant embodiment of the invention provides that the delay calculation term, which is a function of the selected frequency for the signal components from which image data is to be retrieved, is associated with a phase shift direction changing sequence in which the elements are applied as a function of the transducer index with reference to the position of transducers in the array.

A possible sequence is a 0, 1, 0, 1, 0, 1, sequence, corresponding to a $\text{rem}(i/2)$ function, in which "i" is the index of the transducer in the transducer array; where the $\text{rem}(a/b)$ function is the remainder of the division of a by b.

A variant embodiment provides a different sequence, 0, 1, -1, 0, 1, -1, corresponding to a $\text{rem}((i+1)/3)-1$ function, where "i" is the index of each transducer in the transducer array.

A further possible sequence includes the elements 0, 1, 0, -1, 0, 1, 0, -1, corresponding to a $(-1)^{(i+1)/2} \text{rem}(i/2)$ function, where "i" is the index of each transducer in the transducer array.

In this case, when the receive signals are summed, the above mentioned edge effects are substantially reduced in time for the fundamental frequency, while obtaining the highest signal amplification for the sum of harmonic, particularly second harmonic, components, and a reduced time extension of the signal.

In order to further remove edge effects that are considerably reduced and substantially located at the ends of the pulsed sum signal of the fundamental frequency components, a signal having an envelope with smoothed edges may be further provided, for instance, a signal with a triangular envelope or a Gaussian curve, which further reduces, in this case, the amplitude of edge effects in the signal resulting from the sum of fundamental frequency components, while the amplification of the overall receive signal, i.e. the sum of the selected harmonic, particularly second harmonic, components of the signals from the transducers is still high and the characteristics of a short duration of the sum signal are also maintained.

Thus, the inventive method allows to suppress the fundamental frequency components of signals upon received beam focusing, with no massive hardware load and without requiring longer processing or scanning times, unlike prior art Harmonic Imaging techniques.

The present invention addresses an apparatus for implementing this method, particularly an ultrasonic imaging apparatus, comprising at least one ultrasonic probe with a plurality of transmitting transducers and a plurality of receiving transducers. A receiver beamforming unit is connected to the receiving transducers for application of received signal synchronization delays to the individual receiving transducers, with reference to the direction in which transducers are focused to one or more reflection sources. Apparatus is provided for processing received signals, which includes the suppressing or at least attenuating the fundamental frequency component of the received signals. Apparatus sums the received signals from their respective receiving transducers and transforms the sum signals into image data, as well as for displays the image data in the form of graphic images.

According to the present invention, the receiver beamforming apparatus comprises a unit which can be programmed or controlled by programmable control means, and contains the algorithms for calculating the received signal delays for each receiving transducer, which delays are calculated as a function of the transducer position in the array with respect to a predetermined reference point, and based on the steering angle and on a predetermined harmonic of the fundamental frequency of received signals.

According to an improvement of the present invention, the receiver beamforming units are programmed or controlled by apparatus that is programmable to calculate the receiver delays for each receiving transducer in order to generate a change in the phase shift direction, which phase shift is caused by the functional dependence of delays from the selected harmonic frequency, particularly the second harmonic frequency.

In particular, the receiver beamforming unit is programmed or controlled by programmable means in such a manner as to combine the phase shift of the received signals of transducers caused by the application of functional delays and by the dependence thereof from the selected harmonic frequency, particularly the second harmonic, with a phase shift direction changing sequence, composed of alternate "0" and "1" elements. This sequence is defined, for instance, by a $\text{rem}(i/2)$ function, where "i" is the index of the transducer in the transducer array and (a/b) rem function as defined above.

A variant embodiment provides a different sequence, 0, 1, -1, 0, 1, -1, corresponding to a $\text{rem}((i+1)/3)-1$ function, where "i" is the index of each transducer in the transducer array.

Yet a further possible sequence includes the elements 0, 1, 0, -1, 0, 1, 0, -1, corresponding to a $(-1)^{(i+1)/2} \text{rem}(i/2)$ function, where "i" is the index of each transducer in the transducer array.

According to another improvement of the invention, the apparatus further includes means for generating pulsed acoustic beams whose time curve has an envelope with smoothed edges, e.g. a triangular or Gaussian envelope. Thanks to this operation, the received signals from the individual transducers will also have echoes with a smoothed envelope, thereby enhancing system performance. As an alternative to the above, filters may be provided, which operate on received signals to smooth the envelope of received echoes on the basis of the transmitted signals.

10 Further improvements and advantages of the inventive method will form the subject of the subclaims.

The characteristics of the invention and the advantages derived therefrom will appear more clearly from the following description of a non limiting embodiment, illustrated in the annexed drawings.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a greatly simplified view of the receiver arrangement which includes the application of time delays to focusing of ultrasonic beams reflected toward the receiving
5 transducers of an ultrasonic probe.

Figures 2 and 3 show a prior art method, known as the Delay and Sum method, applied to the fundamental frequency component of received signals and to the second harmonic component of received signals.

Figures 4 and 5 illustrate, using a configuration similar to that used in Figures 2 and 3, an
10 aspect of the present invention with reference to ideal conditions.

Figures 6 and 7 show an aspect of the present invention with reference to actual conditions in which the received signals are of the pulsed type, i.e. limited in time.

Figures 8 through 13 show, in a like manner to Figures 4 through 7, the effect of three different modes of phase shift direction alternation between successive received signals of
15 transducers for the purpose of limiting or suppressing the effects shown in Figs. 6 and 7.

Figures 14 and 15 show, in a manner similar to previous Figures, the effects of the use of received signals with a triangular envelope on the signal's fundamental frequency components and on the signal's second harmonic components, respectively.

Fig. 16 shows a block diagram of an ultrasonic imaging apparatus used to implement the
20 inventive method.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a schematic and drastically simplified view of an ultrasonic signal receiving configuration which implies the need of focusing the received beams by imparting delays to windows of reception actuation of the receiving transducers of an array.

Seven transducers are arranged along the x axis, the Figure showing them in spaced positions for graphical convenience, although they are in adjacent positions, i.e., closely arranged, in actual ultrasonic probes.

The transducers are designated with numbers 1 to 7 and the distance from a predetermined reference point, here the origin of the coordinate system, where t is designated as $X_1, X_2, X_3, X_4, X_5, X_6, X_7$, and where the index identifies the corresponding transducer. This notation is consistent with the general mathematical notation that will be used hereafter. Each transducer is identified by an index "i" whose value may be a whole number, which also identifies a certain position thereof in the transducer array, hence a certain distance from a predetermined reference point.

An ultrasonic beam transmitted into a body under examination, hence with a propagation direction Y, penetrates said body under examination. The distance y is proportional to the propagation time from the moment in which the beam is transmitted with the propagation velocity being constant in the body under examination.

The transmitted beam is then reflected by a reflector, designated as C and represented by way of example by a single point for the purpose of graphical convenience.

The reflector is physically equivalent to an ultrasonic wave transmission source, hence the reflected wave is shown in the schematic example as a spherical wave. The dashed arrows R1 to R7 show the directions along which the active receiving surfaces of the transducers are joined to the reflection point C.

As is apparent from the above description, the reflected signal contributions along the different directions R1 to R7 reach the corresponding transducers 1 to 7 at different times. In order to reconstruct the reflected beam, which is formed by the sum of the received signal contributions from all transducers 1 to 7 of the array, different receiver delays must be applied to each transducer, which delays must be calculated on the basis of the transducer position of the ultrasonic wave propagation velocity and generally of the steering angle, that is, the angle

between the point C and the origin of the selected coordinate system, as well as, when necessary, of the distance of the point C from the origin of the coordinate system. Hence, the signals received by each transducer will be synchronized and the appropriate parts thereof, relative to the reflected beam generated by the reflector C, will be summed. It shall be noted that Figure 1 does not show the transmission process in order to illustrate in a clearer manner the reflection process.

Figures 2 and 3 show the theoretical curves of the received signals of three transducers, after the application of the above mentioned delays, relative to the fundamental frequency component and to the second harmonic component, as well as the corresponding sum signals obtained with a prior art method, known as Delay & Sum.

Here, the received beam, i.e. the sum signal, is defined by the following equation:

$$b(t, \theta_0) = \sum_i s_i \left(t - \frac{x_i \sin \theta_0}{c} \right)$$

The beam b is formed by the signal resulting from the sum of the signals of all transducers S_i , to which delays are imparted which are a function of the position x_i of the individual transducers, of the steering angle, and of the ultrasonic wave propagation velocity, and subtracted from the actuation time t of the receiver window of the transducer array, i.e. of the transducer having a zero delay. The delay term that is inserted in the previous equation refers to a scene situated in the far field; if the scene is situated in the near field, then the delay term shall be updated to further account for the distance of the scene from the origin of the selected coordinate system. This update is made by following prior art rules, particularly the well-known dynamic focusing technique, and does not affect or alter in any manner the validity and functionality of the invention. Therefore, for the sake of simplicity, the description below regarding the Delay & Sum method will relate to delays determined for a scene in the far field, while it will be implicitly understood that those delays may be replaced by delays determined for a scene in the near field, as is known in prior art. It shall be noted that the delays imparted to receiving transducers require a synchronization of signals, as shown in Figures 2 and 3, regardless of the frequency thereof, whereby the sum signal involves an amplification of the individual signals of the receiving transducers. In fact, the above equation provides no dependence of the sum signal b from frequency. Therefore, when the traditional Delay & Sum beamforming method is used, the so-called Harmonic Imaging mode, in which second harmonic components of received signals are used to obtain image data, requires further processing to

suppress or substantially drastically reduce the fundamental frequency component of the signal. This is necessary because the signal amplitude at the fundamental frequency is considerably higher than the signal amplitude at the second harmonic frequency, and thereby produces a glare-like effect which prevents Harmonic Imaging processing. In prior art methods, as described in the introduction, other arrangements are used to suppress or drastically reduce the fundamental frequency component, such as the use of adaptive filters or the provision of double transmission firings and the combination of the corresponding received signals to obtain the suppression of the fundamental frequency component.

Figures 4 and 5 show received signals from a number of transducers, more particularly four transducers, which signals are identified as S₁ to S₄ and correspond in Figures 4 and 5 to the signal component at the fundamental frequency and to the signal component at the second harmonic of said fundamental frequency respectively. Moreover, the curve of the signal resulting from the sum of the individual received signals S₁ to S₄ is shown in the two above cases.

The method of the invention provides that the receiver delay to be imparted to each transducer depends on the frequency of the signal component that is selected for imaging, and is linearly dependent on the transducer index, i.e. on the position thereof in the transducer array.

Here, when Harmonic Imaging is only considered, the selected frequency is always twice the fundamental frequency.

The equation to determine the signal consisting of the sum of the received signals from all the receiving transducers, which signal forms the received beam is as follows:

$$b(t, \theta_0) = \sum_i s_i \left(t - \frac{x_i \sin \theta_0}{c} - i \frac{1}{2f_0} \right)$$

where: "i" = transducer index;

f₀:= fundamental frequency;

X_i:= distance of the transducer "i" from a predetermined reference point;

S_i:= receive signal from the transducer "i";

θ₀:= steering angle;

b(t, θ₀):= sum signal.

Here, the time delay introduces a phase shift between the received signals from the individual receiving transducers, which is equal to a half cycle of the fundamental frequency and

is a linear function of "i". As is shown in Figure 4, for the fundamental frequency component, this phase or time shift causes the signals of successive transducers to be always shifted by a half cycle with respect to those of the previous transducer when considering the components at the fundamental frequency f_0 , whereby the received signals of the individual transducers suppress each other in pairs and their sum signal is equal to zero. Regarding the second harmonic components as shown in Figure 5, the introduced phase shift always keeps the received signals in phase, with the sum signal being amplified thereby.

Figures 2 to 5 refer to theoretical, non actual conditions, with the received signals of each transducer being represented as continuous signals. In fact, the received signals are of the pulsed type, as shown in Figures 6 and 7, still referring to the fundamental frequency and to the second harmonic frequency respectively.

This limitation of the signal in time causes drawbacks that are generally known as "edge effects", i.e. partial overlapping of phase shifted pulses. With respect to fundamental frequency components f_0 , these edge effects cause an incomplete removal of their sum signal, as is shown in Figure 6. Regarding second harmonic components, the amplification of their sum signal is reduced and pulses have a longer duration. In these conditions, while the advantages of the invention are not completely lost, the above effects at least partly weaken said advantages.

In order to obviate these undesired side effects, the inventive method provides changes to the calculation of delays to alternately change the phase shift direction between successive received signals of the receiving transducers, in such a manner as to keep the received signals in overlapped positions. This is shown in the examples of Figures 8 to 13, which represent three possible variants of this time shift.

A first variant embodiment of signal phase shift direction change consists in the delay calculation term contained in the following equation:

$$b(t, \theta_0) = \sum_i s_i \left(t - \frac{x_i \sin \theta_0}{c} - \text{rem}(i/2) \frac{1}{2f_0} \right)$$

As is apparent with respect with the previous equation, the only change relates to the delay determining term used to calculate delays for each receiving transducer, wherein the dependence from the $\text{rem}(i/2)$ function replaces the linear dependence from the index "i". This function generates a sequence of alternate "0" and "1" values, depending from the index value, and has been described in greater detail hereinbefore.

The result thereof is apparent from the corresponding Figures 8 and 9. The time shift of the received signals derived therefrom causes a half-cycle shift along the time axis alternately to the right and to the left, whereby the received signals of the individual transducers are aligned in a time shifted manner so as to always remain in substantially overlapped positions or, in any event, to keep the time shift within acceptable tolerances. At the same time, the advantages of a substantial half-cycle shift for fundamental frequency components of a one cycle shift for second harmonic components are unchanged.

The resulting sum signal is shown in the two instances of fundamental frequency components and second harmonic components. This first variant allows a reduction of edge effects, i.e. of the signal parts having a non-zero duration, but involves a considerable amplitude. Also, the non-zero parts of the sum signal appear at the beginning and at the end of the pulse.

Regarding the signal resulting from the sum of second harmonic components, this signal obtains substantially the highest amplification and limits the duration of the sum signal resulting from all the receive signals of transducers.

The second variant embodiment, whose effects are shown in Figures 10 and 11, provides the replacement of the "i" index by a $(\text{rem}((i+1)/3)1)$ function, which produces a 1, 1, 0, 1, 1, ... sequence. The result is immediately visible in Figures 10 and 11. Here again, the received signals of the receiving transducers are still in substantial overlapping positions, like in the previous case.

Regarding the signal resulting from the sum of the fundamental frequency components of the received signal, this signal is shown in Figure 10 and has edge effects, i.e. non-zero parts of the sum signal, that are arranged along the pulse duration and have a reduced amplitude, i.e. equal to a third of the highest amplification, obtained by the sum of all received signals. However, the signal resulting from the sum of second harmonic components here reaches the highest amplification, while the duration of the signal is rather short (about $1/f_0$).

A third variant of the delay calculation term provides a $(1)(i+1)/2\text{rem}(i/2)$ function, instead of the "i" index, to provide a 0, 1, 0, 1, 0, 1, 0, 1, ... sequence. The effects of such delays on the received signals of transducers both at the fundamental frequency and at the second harmonic are shown in Figures 12 and 13.

As is apparent from Fig. 12, the signal resulting from the sum of fundamental frequency components of the received signals of transducers has edge effects, i.e. non-zero parts of the

signal, which are concentrated at the ends of the pulse and have an amplitude of a quarter of the highest possible amplitude.

Regarding the signal resulting from the sum of second harmonic components, once again the highest amplification is reached, but the duration being still rather short (about $1/f_0$).

5 As described above with reference to Figures 8 to 13, these arrangements provide improvements but do not completely suppress edge effects.

10 With particular reference, but without limitation, to the embodiments of Figures 8, 9, 12 and 13, wherein the signals resulting from the sum of fundamental frequency components of received signals have a non zero value in the end portions, advantages may be obtained by providing, in addition to the above, another arrangement for further reducing the above described edge effects.

15 This arrangement is shown in Figures 14 and 15 and comprises the transmission of acoustic beams whose waveform has an envelope with smoothed edges. Figures 14 and 15 show, by way of example, signals received from a few sensors when a pulse having a triangular envelope is used. The envelope shape is only shown in combination with the received signal S1 and is designated with the I symbol.

20 The effect thereof on the signals resulting from the sum of fundamental frequency components and second harmonic components, respectively, are, in one instance, a drastic reduction of the non-zero parts of the sum signal to a fraction of $1/8.7$ of the highest possible amplitude and in the other, second harmonic, instance, a slight attenuation of amplification, substantially to a factor of about 0.77 of the highest amplitude is obtained while keeping acceptable duration levels, substantially at the values that would be obtained without this arrangement.

25 Obviously, other envelope shapes may be provided instead of the triangular envelope, e.g. a Gaussian envelope, or the like.

The advantages of the method of the invention are apparent from the above disclosure. Without having to implement substantial and burdensome fundamental frequency component suppression steps, this suppression may be substantially obtained by simple arrangements in the receiver beamforming process based on the sum of the signal contributions of the individual
30 transducers, i.e. by simply providing an appropriate focusing delay calculation. Yet, further improvement actions would not require considerable increases of processing times and hardware

complexity, thereby providing an inexpensive and fast Harmonic Imaging method. The method of the present invention provides advantages not only in terms of imaging times, but also in terms of a lower apparatus cost, thanks to a smaller number of electronic components and to a consequent simplification of the ultrasonic imaging apparatus.

5 Relating to the above described delay calculation equations, during experiments it has been discovered that the quality of the results improves if the value of the fundamental frequency f_0 is chosen as a frequency greater than the effective fundamental frequency of the transmitted beams. It has been observed that increasing the value of the term f_0 in the equations to about 25% to 50% of the effective value of the fundamental frequency of the transmitted beams obtains
10 the best results.

A further improvement can be achieved by combining the above mentioned increased value of the term f_0 in the delay calculation equation with respect to the fundamental frequency of the transmitted beams, with a high-pass filtering of the summation signal which has a cutting frequency lying between the fundamental frequency and the frequency of the second harmonics.

15 The most probable explanation of this surprising effect can be obtained by considering the spectrum of the signals. The spectrum of the linear contributions to the received beams, i.e. of the contribution which are to be eliminated from the received signals is partially superimposed on the spectrum of the contribution at the second harmonics which is centered at the double frequency of the fundamental frequency, i.e. of the linear contributions to the received signals.
20 The part of the linear contribution of the received signals which is the most difficult to be eliminated or suppressed is the one superimposing on the spectrum of the signal contribution at the frequency of the second harmonic. This superposition or overlay takes effect at a frequency range which lies between the fundamental frequency and the frequency of the corresponding second harmonic. For this reason by increasing the value of f_0 in the delay calculation equations
25 relatively to the value of the effective fundamental frequency, it is possible to suppress or decisively reduce the part of the spectrum of the linear contributions to the signals which is superimposed or overlaid on the spectrum of the contributions at the frequency of the second harmonic, and thus the part of the spectrum of the linear contribution which has the higher damaging effects on the quality of the image. If a part of the spectrum of the linear contribution
30 of the signals, i.e. of the contribution which spectrum is centered at the fundamental frequency still rests after having suppressed the part of the spectrum of the linear contribution overlaid or

superimposed on the spectrum of the contributions at the frequency of the second harmonics, these parts are spread away from the spectrum of the contributions at the frequency of the second harmonic and can be suppressed or eliminated by means of high-pass filtering.

While the delay calculation methods that use the above equations may be directly
5 implemented in hardware, i.e. in transmission beamforming units, without requiring any substantial change to existing apparatus, the invention addresses an ultrasonic imaging apparatus which is particularly adapted for the implementation of the method.

Referring to Figure 16, an ultrasonic imaging apparatus has an ultrasonic probe 10, which includes an array of transducers. The transducers have both receiving and transmitting functions
10 and are alternately connected, in synchronism with the ultrasonic beam transmission and reflected wave reception steps, to a transmission beamforming unit 13 and to a receiver beamforming unit 14 through a switch 12. The signal output from the beamforming unit 13 is forwarded to a processing chain to generate image data therefrom, which processing chain is known and generally designated with numeral 18. Image data is then displayed on a monitor or
15 other display means 19.

In accordance with the present invention, at least the receiver beamforming unit 14 may be controlled by a programmable control unit 15, which has a memory 16 wherein at least one of the beamforming methods, i.e. the delay calculation according to the invention, may be entered by input means 17, such as a keyboard, or the like. Advantageously, thanks to this construction,
20 all the various algorithm types of the invention may be provided in the memory as alternate selections. This permits updating of the beamforming algorithms, i.e. delay calculation algorithms, with improved new-generation algorithms without providing a structural change to the apparatus.

The unit for generating envelope signals is not shown separately from the transmission
25 beamforming unit 13, and is intended as to be schematically contained in unit 13. Here again, the envelope function may be defined in the control unit 15, and selected among different waveforms that may be entered through input means 17 or contained in the memory 16.

Obviously, the invention is not limited to the above description and figures, but may be greatly varied, and particularly the apparatus may be varied as regards construction, and the
30 method may be varied by combination with other well-known imaging methods, all the above without departure from the inventive teaching disclosed above and claimed below.